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Signature: Carl O. McClenny
Carl O. McClenny
Date: October 30, 2001

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of	)	
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WIM HUPKES ET AL	)	
	)	
Serial No. 09/892,417	)	Group Art Unit
	)	
Filed June 27, 2001	)	Examiner
	)	
ON-LINE CALIBRATION PROCESS	)	October 30, 2001

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Sir:

CLAIM TO PRIORITY

Applicants reaffirm the claim for the benefit of filing date of the following foreign patent application referred to in Applicants' Declaration: EPC 00306148.8.

A copy of the application certified by the European Patent Office is enclosed.

Respectfully submitted,

WIM HUPKES ET AL

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Enclosure

TS 1027

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Bescheinigung

Certificate

Attestation

Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten europäischen Patentanmeldung überein.

The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. Patent application No. Demande de brevet n°

00306148.8

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Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

I.L.C. HATTEN-HECKMAN

DEN HAAG, DEN
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Blatt 2 d r Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation

Anmeldung Nr.:
Application no.: 00306148.8
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Anmeldetag:
Date of filing: 19/07/00
Date de dépôt:

Anmelder:
Applicant(s):
Demandeur(s):
SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.
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Bezeichnung der Erfindung:
Title of the invention:
Titre de l'invention:
On-line calibration process

In Anspruch genommene Prioriät(en) / Priority(ies) claimed / Priorité(s) revendiquée(s)

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ON-LINE CALIBRATION PROCESS

The present invention relates to an automatic on-line calibration of input/output models.

It is known in process control systems to use one ore more so-called Quality Estimators (herein after referred to as QE) in the real time prediction of certain, preferably, key process quality and/or property parameters (normally referred to as outputs) from readily available raw process measurements (normally referred to as inputs). Thus, QE is in essence a mathematical input/output process designed at predicting relevant process values.

QE's are usually identified from collected process data. In order to have a useful meaning in real time implementation a QE has to be calibrated using historic quality measurements, which can be taken on-line or off-line depending on the type of process and/or the type of measurement envisaged, so as to minimise, or preferably avoid, any drift in the predicted quality. QE are preferably used in situations which allow rather infrequent and/or delayed measurements of product quality. This may be the case when, for instance, the amount of time needed to produce the measured value is rather long or when the method is relatively costly.

There are a number of difficulties to be faced in the process of automatic on-line calibration of QE such as the occurrence of varying or uncertain process/measurement deadtimes and dynamics between the QE inputs and the measured qualities as well as a phenomenon normally referred to as changing of the process gains, i.e. a drift in the ratio between inputs and outputs.

In order to combat these unwanted situations, it is customary to calibrate QE when the process for which they are applicable is in its so-called steady-state, i.e. in the situation in which the process fluid is uniform and constant in composition, state and velocity at the entrance and at the exit of the operation. Although such calibration will give good results with respect to the system to be monitored, it is still considered to be sub-optimal as dynamic information available is not used since calibration has to wait until the process has reached a steady operating point (thereby causing the need for the presence of a steady-state detector in order to know when calibration can start). Moreover, the conventional QE are only adjustable with respect to model bias conditions such as incorporating new operating points into the process model chosen.

It has now been found that the disadvantages referred to herein before can be minimised or even overcome by applying the process according to the present invention which allows for a real time method for automatic on-line calibration in a robust manner. The Robust Quality Estimator (RQE) according to the present invention provides a more accurate and robust quality prediction which improves the performance of any quality control scheme in which it is applied. For instance, it improves the performance of a linear model predictive controller when the process is such that the steady-state gains and/or the dynamics (such as the deadtime) between the manipulated variables and the controlled quality are varying in an unpredictable manner within certain identified boundaries. Moreover, is can also be used to facilitate closed-loop control of any process variable with a difficult dynamic behaviour.

The present invention therefore relates to a method for automatic on-line calibration of process models for

real-time prediction of process quality from raw process measurements which method comprises the steps of collecting raw process data, processing data collected through a mathematical model to obtain a prediction of the quality, processing this prediction through two independent dynamic transfer functions thus creating two intermediate signals, storing the two intermediate signals obtained as a function of time in history, retrieving, at the time of a real and validated measurement of the quality, from the history the absolute minimum and maximum values of the two intermediate signals in the time period corresponding to a minimum and maximum specified deadtime, which values define the minimum and maximum prediction possible, calculating the deviation as being the difference between the real and validated measurement and the area encompassed between the minimum and maximum prediction possible as obtained, and repeating these steps if the absolute value of the deviation obtained is zero, or, if the absolute value of the deviation obtained is larger than zero, incorporating the deviation into the process model and repeating the steps.

The collection of raw process data to be used in the method according to the present invention can be carried out by methods known in the art. It is customary in process control technology to measure data at a number of points over a period of time. For instance, in refining operations, operating parameters such as temperature, pressure and flow are normally measured at frequent intervals, or even in a continuous manner and they can be stored and processed in many ways as is known to those skilled in the art.

In order to get a prediction of the quality out of the raw process data collected a mathematical model will be used. Examples of mathematical models suitable for QE

are systems known in the art as Multiple Linear Regression, Linear Dynamic Model (in the Laplace transform Domain) and Radial Bias Function Neural Network (optionally with Gaussian function) Depending on the nature of the process model applied and the type of raw material data received, those skilled in the art will select the type of QE best fitting the perceived goal.

An essential step in the method for automatic on-line calibration is the calculation of the minimum and, and maximum prediction possible at the time of the real and validated measurement(s) of the quality. This can be achieved by applying two independent dynamic transfer functions (so-called uncertain dynamics) to the undelayed real time, thus creating two (independent) intermediate signals. These intermediate signals are stored as a function of time in history. This will result in essence in an (uncertainty) area in which the actual process response should be placed and which will become very narrow when reaching the steady-state situation. It is also possible that the uncertainty area is reduced to a line corresponding to the event in which the two independent dynamic transfer functions are identical. The so-called minimum and maximum prediction possible are obtained by calculating from the history the absolute minimum and maximum values of these two intermediate signals in the time period corresponding to a minimum and maximum specified deadtime.

Before reaching the steady-sate situation, the area can be very wide. The state of the art systems will either only calibrate during steady-state or have the risk of making a false calibration in case the real and validated measurement(s) of the quality is within the above mentioned area. The method according to the present invention, however, is specifically designed to calibrate only when the real and validated measurement(s) of the

quality are outside the uncertainty area, thus preventing instabilities in closed-loop.

In the method according to the present invention the calibration process is carried out by calculating the deviation (so-called prediction error) as being the distance between the real and validated measurement and the area encompassed between the minimum and maximum prediction possible as obtained from the earlier calculation.

If the calculation of the deviation as described herein above shows that the absolute value of the deviation obtained is zero, meaning that the validated and real measurement of the quality is within the uncertainty area, the deviation found will not be used as further input in the calibration process but the system will continue by repeating the steps carried out up till now as there is no need to refine the system. If, however, the deviation as calculated shows that the absolute value of the deviation is larger than zero the deviation obtained will be incorporated into the process model and the previous steps will be repeated. The net result will be the generation of a modified, more precise, prediction model which will then serve as the basis for further modifications depending on the level of deviations being observed during the course of the calibrating process.

When incorporation of the allowed deviation into the process model is envisaged with the use of a Kalman filter the result will be that the deviation can be incorporated into the mathematical model by adjusting its linear parameters thereby updating the prediction band and improving the mathematical model. The use of a Kalman filter is well known in the art of process control operations. Reference is made in this respect to "Stochastic Processes and Filtering Theory" by Jazwinski

(Academic Press, Mathematics and Science and Engineering, Vol. 64, 1970). Since Kalman filters are in essence optimal stochastic filters they also filter out, or even eliminate, the noise on the measured quality which makes them very suitable for use in the method according to the present invention.

It should be noted that the use of Kalman filters is not limited to calibration operations which are carried out under non steady-state conditions as it is equally capable of providing useful information when a process is being operated under steady-state conditions. Under such conditions it has the additional advantage that it will reduce the prediction error in the future which makes the QE part of a learning system which is upgrading itself when applied in practice.

In the event that no real and validated measurement of the quality is received, calibration as defined in steps e, f and g is not carried out. The system will repeat steps a-d until a further real and validated measurement of the quality is received.

The calibration process as described in the present invention can be extrapolated for robust multivariable predictive controllers to cover uncertain dynamics in the control model for all the transfer functions between the manipulated variables and the controlled variables.

CLAIMS

1. A method for automatic on-line calibration of process models for real-time prediction of process quality from raw process measurements which method comprises
a) collecting raw process data,
b) processing data collected in step a) through a mathematical model to obtain a prediction of the quality,
c) processing this prediction through two independent dynamic transfers functions thus creating two intermediate signals,
d) storing the two intermediate signals obtained in step c) as a function of time in history,
e) retrieving at the time of a real and validated measurement of the quality form the history the absolute minimum and maximum value of the two intermediate signals in the time period corresponding to a minimum and maximum specified deadtime, which values define the minimum and maximum prediction possible,
f) calculating the deviation as being the difference between the real and validated measurement and the area encompassed between the minimum and maximum prediction possible as obtained in step e), and
g) proceeding with step i) if the absolute value of the deviation obtained in step f) is zero, or, if the absolute value of the deviation obtained in step f) is larger than zero,
h) incorporating the deviation into the process model, and
i) repeating steps a)-h).

2. A method according to claim 1, in which as mathematical model a Multiple Linear Regression model is used.

3. A method according to claim 1, in which as mathematical model a Linear Dynamic Model is used.

4. A method according to claim1, in which as mathematical model a Radial Basis Function Neural Network is used.

5. A method according to one or more of claims 1-4, in which in step h) the deviation incorporated into the model bias, thereby upgrading the prediction model.

6. A method according to one or more of claims 1-4, in which in step h) a Kalman filter method is used to incorporate the deviation into the mathematical model by adjusting its linear parameters thereby upgrading the prediction ands improving the mathematical model by self learning.

7. A method according to claim 6, in which the Kalman filter is used in step h) under non steady-state conditions of the process.

A B S T R A C T

ON-LINE CALIBRATION PROCESS

Method for automatic on-line calibration of process models for real-time prediction of process quality from raw process measurements by collecting raw process data, processing data collected through a mathematical model to obtain a prediction of the quality, processing this prediction through two independent dynamic transfers functions thus creating two intermediate signals, storing the two intermediate signals obtained as a function of time in history, retrieving, at the time of a real and validated measurement of the quality, from the history the absolute minimum and maximum values of the two intermediate signals in the time period corresponding to a minimum and maximum specified deadtime, which values define the minimum and maximum prediction possible, calculating the deviation as being the difference between the real and validated measurement and the area encompassed between the minimum and maximum prediction possible as obtained, and repeating these steps if the absolute value of the deviation obtained is zero, or, if the absolute value of the deviation obtained is larger than zero, incorporating the deviation into the process model and repeating the steps. By using a Kalman filter method for incorporating the deviation into the mathematical model its linear parameters will be updated, thereby improving the model. The calibration process with the Kalman filter can be applied under non steady-state conditions.

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